CO-PACKAGED CONTROL CIRCUIT, TRANSISTOR AND INVERTED DIODE

RELATED APPLICATION

[0001] This application is a continuation-in-part of U.S. Application Serial No. 10/377,683 to Stephen Oliver and Hugh D. Richard, entitled "Semiconductor Package for Series-Connected Diodes," filed February 28, 2003, which claims the benefit of U.S. Provisional Application No. 60/408,519, filed September 4, 2002, entitled "Tandem Diode Package with One Flip Chip." The disclosures of 10/377,683 and 60/408,519 are incorporated by reference herein in their entirety.

FIELD OF THE INVENTION

[0002] The field of the invention is electronic packaging of switching device. Specifically, a diode is copackaged with a power switch and control circuitry.

BACKGROUND OF THE INVENTION

[0003] As shown in Figure 1, a combined chip, consisting essentially of a power switch 10, such as a MOSFET, and an integrated circuit control chip 4 mounted directly on a source electrode 13 of the power switch 10 by an adhesive 191, is known. In the example shown in Figure 1, the adhesive 191 is an electrically conductive adhesive that also serves to couple the bottom electrode 5 of the control chip 4 directly to the source electrode 13 of the power switch 10. Alternatively, it is known to use an adhesive 191 that is electrically insulating, repositioning the electrode 5 to the same surface of the control chip 4 as the other electrodes 7, 9. Then, the electrode 5 must be electrically coupled to the source electrode 13 by any

conventional process, such as by a wire bonding process. Such a combined chip may be packaged by surface mounting the drain electrode 11 of the MOSFET 10 on a printed circuit board 6 (a contact pad of which is partially shown), electrically connecting the drain of the MOSFET 10 to other electronic components by wire traces, for instance. However, a disadvantage of mounting a conventional combined chip directly to a PCB is that thermal management of the power switch 10 is limited by the presence of the PCB adjacent to the combined chip.

[0004] Also, conventional power factor correction circuits connect a separately packaged power switch with a separately packaged diode, such that the drain electrode of the power switch, such as a MOSFET 10, is electrically connected to the anode of the diode. However, such an architecture requires inventory and supply management, thermal management and electrical contacts for each of the separately packaged power devices, as both the power switch and the diode produce heat. Also, separately packaging the components and integrating the components in an electronic circuit requires a substantial amount of space for making electrical connections between the separately packaged component parts.

[0005] In addition, a conventional diode die is configured to have a wire bondable anode electrode on one side of the diode die and a solderable cathode electrode on the opposite side of the diode die. The anode electrode is wire bonded to one pin of a lead frame. The cathode electrode, which is solderable, is soldered to a copper pad of the lead frame, and the copper pad is electrically connected to another pin of the lead frame. Then, the pad, the diode die and a portion of the pins are packaged by encapsulation, such as in an epoxy resin encapsulant, to protect the diode die, allowing the packaged diode die to be connected to an external electronic circuit, such as a printed circuit board (PCB).

SUMMARY OF THE INVENTION

[0006] A diode, a power switching device and an integrated circuit controller for the power switching device are copackaged in a discrete electronic package. For example, the copackaged electronic device may be used to replace a plurality of discrete elements of a conventional alternating current (AC) to direct current (DC) converter using power factor correction (PFC).

[0007] In one embodiment, the copackaged electronic device comprises an encapsulated, discrete device, including a lead frame, a power switching device, an integrated circuit controller for switching of the gate electrode of the power switching device and a diode. The lead frame has a pad having an electrically conducting mounting surface and a plurality of leads for connecting to an external circuit, such as an AC to DC converter. The power switching device, such as a MOSFET, has a first electrode (e.g. drain) on a first surface and two additional electrodes (e.g. source and gate) on an opposite surface. The first surface is mounted on the mounting surface of the pad. The integrated circuit (IC) controller is mounted on one of the two additional electrodes and may be operably electrically coupled to the two additional electrodes by any conventional process, such as soldering and/or wire bonding, for controlling switching of the power switching device. The diode may be a flip chip and may have its anode electrode electrically mounted to the mounting surface of the pad. For example, the diode is laterally removed from the power switching device in a side-by-side arrangement. Leads of the lead frame are electrically coupled to the pad, the cathode of the diode, control electrodes of the IC controller and at least one of the additional electrodes of the power switching device, such that the copackaged electronic device may be operably connected to an external circuit.

[0008] In one example, a copackaged electronic device is packaged in a power package, such as a TO220, D2pak, TO220FP or TO247, while including the control circuit and the power switching device together with the diode. The number

of discrete parts, the number of individual connectors, and the number of wire bonds or wire traces between components are reduced compared to conventional use of discrete components of an AC to DC converter with power factor correction. For example, a through hole lead frame package may be mounted directly to a heat sink via an exposed back surface of the lead frame pad, greatly improving and simplifying thermal management of the heat generating power switching device and diode.

[0009] In one embodiment of the present invention, an integrated, electronic package has a plurality of diodes in series electrical contact mounted on an insulating layer on a portion of an electrically conductive contact pad. Optionallyh, a common heat-sink may be mounted to the opposite side of the lead frame providing thermal management of each of the heat-generating power devices. One diode may be a conventional diode with an anode of a wire bondable material, such as an aluminum, and a cathode of a solderable material, such as a solderable metal, e.g. a copper including, without limitation, solderable copper alloys. The solderable cathode may be joined to the electrically conductive contact pad by a thin layer of solder between the cathode and the lead frame, for example. The other diode may be an inverted diode. An inverted diode comprises a cathode of a wire bondable material and a solderable anode and, otherwise, may have a common semiconductor die architecture with the conventional diode. For example, the two diodes are copacked with an integrated circuit controller and/or a power switching device.

[0010] In one embodiment, a passivation layer surrounds the anode of the inverted diode. The passivation layer protects the termination structure of the inverted diode, allowing the anode to be directly joined to the electrically conductive surface of a die pad. The passivation layer electrically insulates the termination structure from the conductive lead frame.

[0011] One advantage of the copackaged device is that the size of a power factor correction circuit is reduced. Another advantage is that fewer wire bonds are required, reducing circuit resistance and inductance. Yet another advantage is that

the number of external leads for connecting to a circuit board, such as a PCB, is reduced compared to a conventionally mounted transistor, integrated circuit controller and diode. Yet another advantage is that thermal management of the heat generating components is simplified and improved by copackaging the power switching device and the diode.

[0012] Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

[0013] Figure 1 shows an integrated circuit mounted on a switching device, which is mounted on a pad (partially shown).

[0014] Figure 2 shows an embodiment of the present invention.

[0015] Figure 3 shows a circuit diagram of the embodiment shown in Figure 2.

[0016] Figure 4A shows a cross-section inverted diode having a solderable anode surrounded by a passivation layer, according to the present invention.

[0017] Figure 4B shows the cross-section of the inverted diode of Figure 4A, mounted on a pad (partially shown).

[0018] Figure 5 shows another embodiment of the present invention.

[0019] Figures 6A and 6B illustrate a diode with a passivation layer.

[0020] Figure 7A illustrates use of diodes of Figures 6A and 6B in the embodiment of Figure 5.

[0021] Figure 7B illustrates diodes mounted on opposite sides of a die pad in another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] Now referring to Figure 2, one embodiment of a copackaged electronic device 2 comprises a single, 600 Volt (V) fast recovery diode 20 electrically connected to the drain electrode 11 of a MOSFET 10 via an electrically conductive pad 32 of a lead frame 30. The diode 20 is laterally removed from the MOSFET 10 on the mounting surface of the pad 32 and the anode electrode 24 of the diode 20 is electrically mounted on the mounting surface of the pad 32. For example, the diode 20 may be a flip chip diode (e.g. inverted), having the cathode electrode 24 of the diode 20 wire bonded 17 to a lead 12 of the lead frame 30. For example, a contact pad 40 electrically couples a wire bond 17 to the lead 12. Flip chip mounting of the diode 20 greatly simplifies the assembly process and reduces the number of wire bonds required, which reduces wire bond resistance and inductance, improving the efficiency of the discrete copackaged electronic device 2 of Figure 2 compared to devices using a conventional diode.

[0023] In one embodiment, an integrated circuit 4 (IC) is mounted on the source electrode 13 of the MOSFET 10 by a layer of electrically conductive adhesive 19, such as solder, an adhesive tape or an epoxy, and is electrically coupled to an electrode 5 on the bottom of the IC 4 to the source electrode 13. Alternatively, the IC 4 may have all of its electrical contacts 5, 7, 9 on the same major surface, the layer of adhesive may be electrically insulating, and electrode 5 may be electrically coupled to the source electrode 13 by any conventional process, such as by a wire bond. For example, Figure 1 shows an electrical contact 7 on the IC 4 that is electrically coupled by a conventional wire bond 17 to the gate electrode 15 that is used for controlling the switching of the MOSFET 10. The IC 4 is also electrically coupled to the control leads 14, 16 of the lead frame 30, as shown in Figure 2, for example. As shown in Fig. 3, the leads 14, 16 provide for coupling of the IC 4 to a power factor correction circuit 30, which provides electrical signals or voltages to the IC 4, as is known in the art of power electronics.

[0024] The mounting surface 33 of the pad 32 of the lead frame 30 may be made of any electrically conductive material, such as a homogenous metal layer. For example, the entire pad 32 is a metal, such as a copper or an aluminum metal, which improves thermal heat transfer through the pad 32. In one example, the copackaged electronic device 2 is packaged using an encapsulant (not shown), such as an epoxy resin, to encapsulate the electronic components, but leaving the back surface 35 of the pad 32 exposed, allowing a heat sink (not shown) to be directly coupled to the pad 32. Thus, thermal management of the heat generating components, the MOSFET 10 and the diode 20, is greatly simplified compared to the thermal management required for use of conventional discrete components.

[0025] The wire bonds 17 may be made by any conventional process, such as a conventional wire bonding process using gold or an aluminum. The anode electrode 24 of the diode 20 is electrically coupled to the pad 32 of the lead frame 30. For example, an electrically conductive adhesive 19, such as a solder, an adhesive tape or a continuous, metal-filled epoxy, may be used to electrically couple the electrode 11 of the MOSFET 10 and the anode electrode 24 of diode 20 to the mounting surface 33 of the pad 32 of the lead frame 30. Preferably, the anode electrode 24 of the diode 20 is solderable, and the thermal resistance of the pad 32, the anode electrode 24 and the layer of solder 19 is reduced, allowing efficient heat removal from the diode 32.

[0026] In one embodiment, a copackaged device 2 is fabricated by manufacturing a conventional MOSFET 10 and a flip chip diode 20, such that the cathode 22 of the diode 20 is made of an aluminum, and the anode electrode 24 is made for joining to the mounting surface 33 of the pad 32 of the lead frame 30. Preferably, the anode electrode 24 is made of a solderable metal, such as copper or a copper alloy, and the anode electrode 24 is surrounded by a passivation layer 26, which may be made of an insulating epoxy, for example. The passivation layer 26 shields the termination structure 28. For example, during joining of the anode

electrode 24 to the lead frame pad 32, the passivation layer 26 shields the termination structure 28 from contacting solder 2 or electrically conductive adhesive 2.

[0027] In one embodiment, both the drain 11 of the MOSFET 10 and the anode electrode 24 of the diode 20 are mounted on the same surface 33 of the pad 32 of the lead frame 30 in a side-by-side configuration, allowing the back side 35 of the pad 32 to remain exposed after the electronic devices 4, 10, 20 are encapsulated by an encapsulant. The IC 4 may be mounted on the MOSFET 10 either after the MOSFET 10 is mounted on the pad 32 or prior to mounting the MOSFET 10 on the pad 32. In one embodiment, the IC 4 is mounted on the MOSFET 10, and then both the MOSFET 10 and the diode 20 are joined to the pad 32 simultaneously in a common soldering step.

[0028] For example, contacts 3, 7, 9 on the surface of the IC 4 are then wire bonded to the gate electrode 15 of the MOSFET 10 and to external leads 14, 16, as shown in Figure 2. Input leads 14, 16 may be connected to an external circuit board (not shown) to provide voltage signals for the IC 4 to control the switching of the MOSFET. Output lead 12 outputs the resulting output voltage of the copackaged device, and the source lead S and drain lead D are used as external connections to the source and drain electrodes S, 11 of the MOSFET 10. Other configurations of contacts and leads may be used to integrate the copackaged device in a power factor correction circuit, for example, as is known in the art.

[0029] Preferably, by copackaging the IC 4, MOSFET 10 and diode 20 as described, the copackaged device 2 is capable of being housed in a device having the same form as a conventional diode package, such as a D2-pak, TO220 or TO247. For example, a 5-pin TO220 standard configuration may be fabricated by enclosing the IC 4, MOSFET 10 and diode 20, as shown in Figure 2 within a resinous encapsulant. Preferably, the back surface 35 of the pad 32 remains exposed for mounting a heat sink (not shown) to the pad 32, enhancing heat transfer by limiting the thermal resistance between the heat generating components 10, 20 and the heat

sink. Copackaging of these heat-generating power devices 10, 20 simplifies thermal management by using a common heat sink, for example. Alternatively, a 6-pin or 7-pin package may be used, offering additional output pins for connecting with an external electrical circuit.

[0030] As shown in Figure 5, two 300 V diodes 120, 121 are connected in series in a tandem diode package 220, creating a single 600 V fast diode for continuous mode power factor correction. As shown in Figure 5, a tandem diode circuit 220 comprises a first diode 120, an inverted diode 121, a diode contact pad 129, a pin contact pad 40 and an electrical lead 12. One diode 120 is wire bonded from its anode 24 to a mounting surface of a conductive die pad 30. The die pad 30 is integrally attached to a central pin D. An inverted diode 121 has a cathode 122 that is wire bonded to a pin contact pad 40. The contact pad 40 is integrally attached to an electrical lead D. Alternatively, lead D may be separated from contact pad 40, and the contact pad 40 may be coupled to the lead D by any conventional process, such as wire bonding. Thus, pin D is electrically coupled to the anode 24 of one diode 120 and lead 12 is electrically coupled to the cathode 122 of the tandem diode package 220, such that the tandem diode package 220 may be connected in a circuit with the copackaged MOSFET 10 and IC 4.

[0031] The contact pad 129 may be made of any electrically conductive material. Preferably, the contact pad 129 is a metal, such as a copper or an aluminum metal and is insulated from the mounting surface 33 of the lead frame 30 by an insulating layer 139, such as an insulating adhesive layer or ceramic layer. Wire bonding may be completed by any conventional process, such as a conventional wire bonding process using gold wires. Each of the diodes 120, 121 are electrically bonded to the contact pad 129. For example, a solder or conductive adhesive, such as a continuous, metal-filled epoxy, may be used to make an electrical connection between the cathode of the first diode 120 and the anode 122 of the inverted diode 121 via the contact pad 129.

[0032] In one embodiment, the tandem diode package 220 is fabricated by manufacturing one conventional diode 120 and one inverted diode 121. The conventional diode 120 may be prepared by any conventional process. The semiconductor die 128 of inverted diode 121 may be made by the same process; however, the cathode 124 is made of a material for wire bonding between the cathode 124 and the contact pad 40, and the anode 122 is made for joining to the tandem diode contact pad 129. Preferably, the cathode 124 is of an aluminum, such as a wire bondable aluminum alloy. Preferably, the anode 122 is made of a metal and is surrounded by a passivation layer 127, which may be made of an insulating epoxy, for example. The passivation layer 127 protects the termination structure 126, during joining of the anode 122 to the tandem diode contact pad 129, from contacting the electrically conductive material adhering the anode 122 to the contact pad 129. More preferably, the metal of the anode 122 of the inverted diode 121 is of a solderable metal.

[0033] For example, both semiconductor diode dies 128 may be made on the same wafer by applying and patterning anodes, cathodes, termination structures and passivation layers as appropriate on the anode and cathode sides of each semiconductor device. The semiconductor diode dies are then separated, such as by sawing or laser cutting the dies from the wafer. The conventional diode 120 has its cathode 22 soldered to the contact pad 129, and the inverted diode 121 has its anode 122 soldered to the contact pad 129. Preferably, both of the diodes 120, 121 are mounted on the same surface of the lead frame 30 in the same die bonding step. Then, both diodes 120, 121 are wire bonded to their respective wire bonding points. Packaging of the tandem diode structure 220 is then completed as previously addressed. Alternatively, the tandem diodes 120, 121 may be mounted first on a tandem diode contact pad 139, and then the contact pad may be mounted on the lead frame 30 prior to wire bonding of the diode electrodes.

[0034] A plurality of diodes 120, 121 may be connected in series by this process, forming a very fast, high voltage diode package. At high voltages, a tandem diode package 220 has a faster reverse recovery time than a single diode of the same rating. For example, two fast diodes 120, 121 connected in series on a single contact pad 139 may be housed in a standard power diode package, such as a TO220, D2-pak, TO220FP or TO247, without any need of internal insulation. For example, parallel pins 144, 146, 148 extend from one side of the lead frame 130 as shown in Figures 7A.

[0035] As shown in Figures 7A and 7B, tandem diodes 120, 121 may be packaged in series by placing two identical lead frames 30 back-to-back and separated by an insulating layer 130. For example, the tandem diodes 120, 121 are then mounted on one surface and wire bonded to contact pads 140, 141, which may be wire bonded to electronic devices on the opposite surface of the lead frame 30 by wire bonds 153 as shown in Figure 7A. In this example, the surface of the lead frame 30 serves as a contact pad 139, such that the tandem diodes 120, 121 are connected in series.

[0036] For example, the lead frame 30 may comprise a composite structure having an electrically conducting top surface 137 and an electrically conducting bottom surface 138 separated by an electrically insulating layer 130 sandwiched between the top surface and the bottom surface. For example, the electrically insulating layer 130 may be a thermally conductive layer of a phase change sheet, a tape, an epoxy, a dielectric coating, a boron nitride layer, a silicone grease or a silicone/boron nitride composite.

[0037] In one embodiment, the lead frame 30 has a plurality of diodes, including at least one inverted diode with a passivation layer around the anode, mounted in series on only one surface of the lead frame 30. The opposite surface of the lead frame 30 may be exposed for dissipation of heat. For example, the opposite surface thermally connects to a heat sink (not shown), which extracts heat from the

diode package efficiently. In this alternative embodiment, the MOSFET 10 and IC 4 may be copackaged in a separate, discrete package that is mounted on the same heat sink as the diode package. For example, the two discrete electronic packages may be mounted side-by-side or on opposite sides of a common heat sink.

[0038] Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the examples herein, but only by the claims themselves.